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ORIGINAL PAPER

Integrated approach for understanding spatio-temporal changes in forest resource distribution in the central Himalaya

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Abstract: Intense anthropogenic exploitation has altered distribution of forest resources. This change was analyzed using visual interpretation of satellite data of 1979, 1999 and 2009. Field and interactive social surveys were conducted to identify spatial trends in forest degradation and data were mapped on forest cover and land use maps. Perceptions of villagers were compiled in a pictorial representation to understand changes in forest resource distribution in central Himalaya from 1970 to 2010. Forested areas were subject to degradation and isolation due to loss of connecting forest stands. Species like *Lantana camara* and *Eupatorium adenophorum* invaded forest landscapes. Intensity of human pressure differed by forest type and elevation. An integrated approach is needed to monitor forest resource distribution and disturbance.

Keywords: characterization, forest, central Himalaya, integrated approach, distribution, spatio-temporal

Introduction

Forest resources provide an array of socio-economic goods and ecological services. During the last 8000 years, global forest cover has declined by 45% and the net loss of forests between 2000 and 2005 was 7.3 million ha (www.cbd.int/forest/about.shtml). Globally, around 32,300 ha of forest disappear daily and about 13 M ha of forest is lost each year, of which 6 M ha is primary forest (Butler 2006). The main reason for forest degradation and loss is increasing anthropogenic activity (Mayaux et al. 2005). Changes result from alterations in management practices and social, economic and political forces controlling land use practices (Flenley 1979; Di Castri and Hadley 1988; Horn and Sanford 1992).

Importance of land use land cover (LULC) dynamics in general and forest cover dynamics in particular is recognized by the International Geosphere Biosphere Programme (IGBP), the International Human Dimension Programme (IHDP) on Global Environmental Change (GEC), the United National Framework Convention on Climate Change (UNFCC), the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) and other similar programs. In India, forest cover maps have been prepared biennially since 1987 using satellite remote sensing techniques (ISFR 2009). Forest cover is mapped as very dense (canopy density >70%), moderately dense (40%–70%), open (10%–40%) forest and scrub (<10%). The minimum mappable area is 1 ha and the distinctive reflectance of tree cover is used to distinguish forest from other cover classes. This type of mapping exercise does not distinguish density classes (Joshi et al. 2001; Roy and Joshi 2002) and other changes beneath the canopy. This level of detail requires information collected by field survey. Resulting maps provide more information about interactions between people and forests.

Satellite remote sensing was first applied to vegetation studies around the mid 1980s in the Central Himalayan region (Singh and Kaur 1985; Tiwari et al. 1985; Shah 1982; Singh et al. 1984; Rai et al. 1984; Rai 1995). In one of the earliest works, Van Es (1972, 1974) used aerial photographs (AP) and Landsat images to distinguish 11 different vegetation classes in forest vegetation of the Doon valley. Pangtey and Joshi (1987) studied changes in land use practices in the western Himalaya and their influence on surrounding forests. Studies by Murthy and Pandey (1978), Gaur et al. (1985), Schroeder (1985), Stone (1990), Farooque (1992) and Badooni and Negi (1995) dealt with changes in socio-economic conditions and related changes in land use practices of people inhabiting the Himalayan region. Kawosa (1988) inventoried and mapped Himalayan resources using Landsat images. Rathore et al. (1997) studied changes in forest cover in central Himalaya and observed 3%–5% reduction in the area under forest during 1973–1989. Similar results were reported by Pant and Kharkwal (1995) for Jaunpur block and Pant and Roy (1990) and Pant et al. (2000) for Mussorrie block in Tehri Garh-

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wal during the year 1960-85. More focused monitoring of natural resources in the Himalaya has identified LULC changes (Singh et al. 1984; Singh et al. 1985; Tiwari et al. 1985), their patterns (Sahai and Kimothi 1994; Rathore et al. 1997; Rao and Pant 2001; Joshi et al. 2003; Joshi and Gairola 2004) and degradation (Wakeel et al. 2005; Prabhakar et al. 2006; Yu et al. 2007; Gairola and Joshi 2008; Gautam and Joshi 2009; Munsi et al. 2010a and 2010b). These authors advocated use of remote sensing for resource evaluation but highlighted the limitations of remote sensing to map forest resource degradation in terms of changed forest density and changes beneath the canopy cover.

We followed an integrated approach for understanding changes in forest resource distribution in central Himalayan landscapes by comparing maps prepared from satellite remote sensing data at intervals of 10–20 years. We also carried out field surveys and interviews of local people to identify and describe forest degradation.

Materials and methods

Study area

This study was conducted in Nainital district, Kumaun Himalaya, at 29º 14′ 50.86″ – 29º26′01.44″ N and 79º 16′ 12.11″– 79º 28′ 19.22″ E (Fig. 1). The area covered about 400 sq km and mainly comprised the transitional zone between the Shiwalik hills and the lesser Himalayan ranges. The study area was bounded by the Baur and Nihal rivulets. This study area was an agro-silvicultural ecotone with high human density and supporting mixed practices of subsistence agriculture, livestock rearing, extraction of forest resources and easy accessibility to them. A unique feature of this south-western part of the Nainital hills is that in a straight-line distance of about 22 km, elevations rise sharply from 300 m to 2,600 m AMSL. South of this area lies the sub-montane region of the outer Himalaya, the *terai-bhabar* belt, and further south lies the Gangetic Plain. There are seven major forest types in the area, *viz. Shorea robusta* (sal), mixed *Shorea robusta – Pinus roxburghii* (chir pine), mixed pine - broad leaved, *Pinus roxburghii*, *Quercus leucotrichophora* (Banj oak), *Cupressus torulosa* (surai) and mixed high-altitude oak (Tiwari et al. 1985).

Satellite data

We used satellite images from the Landsat series that were available on the Global Land Cover Network (GLCN) for research and academic purposes. We set the year 1979 as our baseline for assessing changes in forest resource distribution. Landsat images were not available after 2003 so we used IRS LISS III datasets of 2009 for comparative study. Forest resource changes over three decades might reflect policy interventions but not provide details of resource utilization. To identify changes in resource use we studied a dataset from 1990 (Fig. 2). Satellite data of Landsat MSS (Multispectral scanner) data for 19 November 1979, Landsat TM (Thematic mapper) data for 15 November 1990 and IRS-P6 LISS III (Linear Imaging Self-Scanning System) data for 1 October 2009 were used for the study.

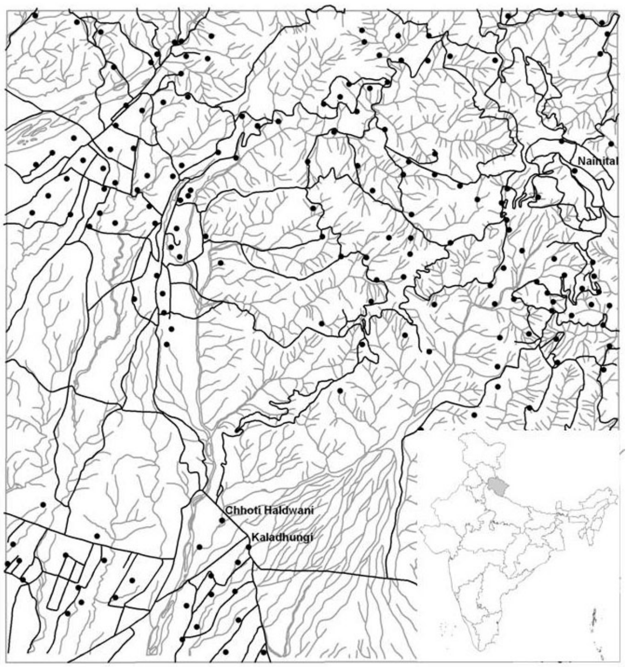

Fig. 1: Location of study area

Ancillary data

Ancillary information and data required for analysis and interpretation of satellite data were collected from various primary and secondary sources. A field and ground-truth exercise was carried out to obtain information about LULC. Survey of India topographical sheets at 1: 50,000 (53 O/7 and 53 O/8) were used for ground survey and preparation of base maps. Uttarakhand Forest Department Working Plans for Nainital Forest Division and Ramnagar Forest Division for the years 1998–1999 to 2007–2008 and 2008–2009 to 2017–2018 were also used. Administrative boundary maps from Revenue Department, District Collectorate, Nainital were procured.

GIS & image processing system

Imagery collected by satellites requires processing to extract information related to forest cover distribution and land use. Image processing is supported by information collected during fieldwork, from other legacy databases (*e.g.* topographic sheets and thematic maps) and instruments used during fieldwork. GPS and magnetic compass were used for ground-truthing, field navigation and survey. Erdas Imagine 8.7 was used for satellite pre-processing and visual interpretation was carried out in ArcGIS 9.1. Documentation, analysis and presentation of data were conducted with MS Office 2007. Dell machines (3GB RAM) with Windows® operating system was used for data storage and software support.

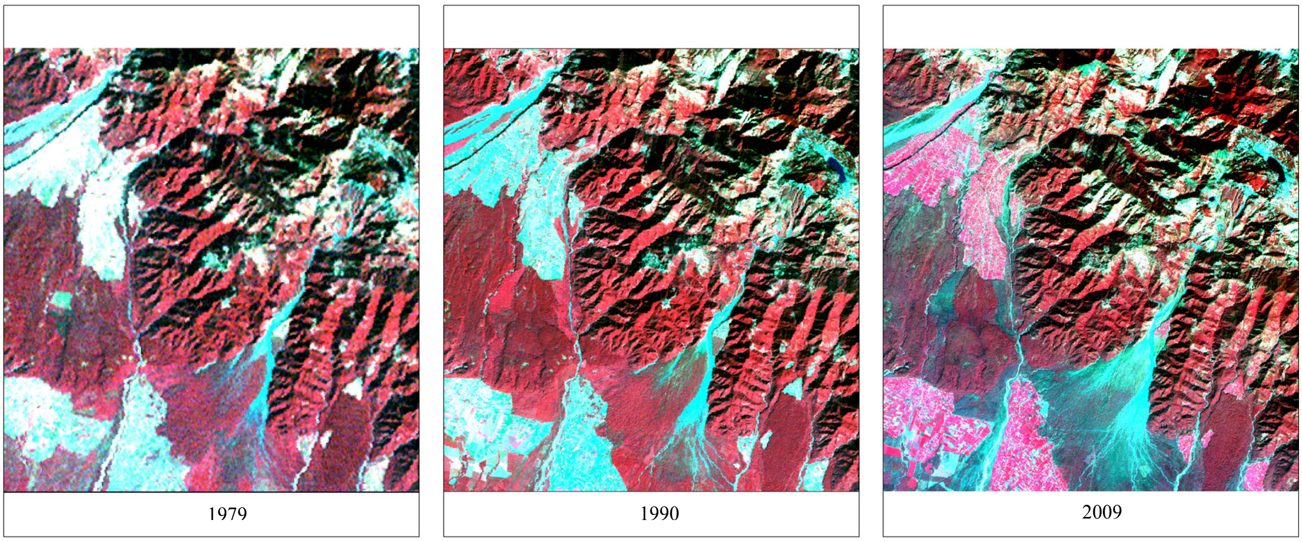

Fig. 2: False color composite of 1979 (Landsat MSS), 1990 (Landsat TM) and 2009 (IRS P6 LISS III) in study area

Research methods

Methods of data collection for assessing spatial and temporal changes in forest resource distribution patterns were aimed at achieving logically valid results. Data collection involved (1) selection of optimal satellite data, (2) satellite data pre-processing, (3) preliminary interpretation, (4) field visit, (5) visual interpretation (6) verification of map, (7) change detection and analysis, (8) mapping invasiveness and (9) post change-detection analysis.

Selection of optimal season data

Ideally, two-season datasets should be used to extract information on vegetation types depending on forest phenology, *i.e.* optimal growth season and leaf fall season. But, for the Himalayan region, where completely cloud and snow free images are few, data were analyzed for a single season only. This did not compromise accuracy of interpretation because forest types were similar in nature and phenological variations were captured during fieldwork. Since post-monsoon datasets are typically cloud free and have maximum reflectance from all vegetation classes, we used datasets from post-monsoon images. Moreover, datasets available on the GLCN matched requirements of the study.

Satellite image pre-processing

Satellite data downloaded from GLCN website were in TIFF format. All bands were imported in Erdas Imagine 9.3 and layer stacked. A false color composite (FCC) was formed for heads-on visual interpretation. A fly-through of entire images was carried out for visual discrepancies and mismatching across bands. Landsat satellite data provided by GLCN were radiometrically and geometrically corrected (ortho-rectification with UTM/WGS 84 projection). Dataset accuracy was at sub-pixel level. For the IRS P6 LISS III dataset we applied the same principle for radiometric and geometric correction in Erdas Imagine 9.3. Distinctive features such as road intersections or stream confluences that were clearly visible in the image were used for geometric correction. To carry this out, uniformly distributed common Ground Control Points (GCPs) were selected and marked with error less than a pixel and images were re-sampled using the nearest neighbor method. Area of Interest (AOI) of the study area was extracted from topographic sheet and was used to clip satellite images.

Preliminary interpretation

A base map was prepared at 1:50,000 scale. Visual interpretation of satellite imagery was done using preliminary interpretation keys based on the image interpretation elements. A number of primary thematic maps including drainage, forest, road and settlement maps were prepared at scale 1:50,000 and the information required for this purpose was extracted and derived from SOI topographic sheets and other maps.

Satellite data were visualized on computers. During the first level inspection and visualization, few patches varied between images. Various enhancement techniques such as linear stretching and non-linear stretching were used to bring out some of the non-forested patches and gaps. We used a customized classification scheme to identify changes in forest cover type and density. Non-forest classes were identified as per the classification of IGBP (Table 1).

Field visit

We ground-truthed the FCC during field visits. Unique tonal characteristics were visited or looked upon from high hilltops. Magnetic compass was used for direction of the maps and observed areas. A GPS database was created using location, elevation and various LULC types. This database was used for visual interpretation of satellite data and accuracy assessment. The interpretation key used for forest cover and land use classification

is show in Table 2.

Table 1: Classification scheme

LULC class	Description
Evergreen (dense) forest (Ev-d)	Forest area with evergreen/semi-evergreen species and canopy density more than 40%
Evergreen (open) forest (Ev-o)	Forest area with evergreen/semi-evergreen species and canopy density between 10% and 40%
Deciduous (dense) forest (Dd-d)	Forest area with deciduous species and canopy density more than 40%
Deciduous (open) forest (Dd-o)	Forest area with deciduous species and canopy density between 10% and 40%
Scrub (Sc)	Area with less than 10% of canopy density
Plantation (Pl)	Area with commercial or other timber production through plantation
Agriculture (Ag)	Area under crop cultivation
Lake (Lk)	Lakes/ponds in the study area
River (Rv)	River and river beds in the study area
Settlement (Set)	Rural, semi-urban or urbanized area primarily used by and for human habitation

Table 2: Interpretation Key

LULC class	Tone/ colour	Texture	Shape	Site
Evergreen (dense) forest (Ev-d)	dark red	Smooth-rough	Irregular	>1,000 m
Evergreen (open) forest (Ev-o)	light red	Rough	Irregular	>1,000 m
Deciduous (dense) forest (Dd-d)	dark to medium brownish red	Rough	Irregular	<1,000 m
Deciduous (open) forest (Dd-o)	dark to light brownish red	Smooth-rough	Irregular	<1,000 m
Scrub (Sc)	dark tan	Rough	Irregular	Scattered
Plantation (Pl)	bright red	Smooth	Regular	<1,000 m
Agriculture (Ag)	pinkish	Smooth	Regular	scattered more <1,000 m
Lake (Lk)	whitish/greyish	Smooth	Varying	
River (Rv)	deep blue	Smooth	Irregular	
Settlement (Set)	very bright white	Medium	Irregular	scattered

Visual interpretation

On screen visual interpretation, one of the major methods used for interpreting satellite data was applied. It is effective and efficient for small study area unlike digital interpretation techniques (Rafieyan et al. 2008). Digitization was used to capture specific areas of interest. Interpretation was carried out in ArcView GIS 3.2. A hierarchical interpretative scheme was devised in which directly observable features such as water channels, water bodies, built-up areas were identified and interpreted. Stratification of the target area, based on color, texture and pattern of the imagery was carried out and general features of the area being mapped were noted. Forest cover and land use patterns were identified with reference to the classification scheme (Table 1) and some of the additional information including ground conditions and heterogeneity of the area.

At first level classification, forest and non-forest classes were delineated. Detailed classes were further deciphered based on field data. Shadowed areas were put to corresponding classes on the basis of field data. To increase accuracy, contour, aspect and slope were used to differentiate between forest types. For overall interpretation the scale was kept constant and a forest cover and land use map for 2009 was prepared. The same vector layer was displayed over other datasets to prepare maps for the years 1990 and 1979. Polygons were modified to map the change areas for other periods. For unchanged areas the same polygons were retained. With repetitive editing of polygons forest cover and land use maps for 2009, 1990 and 1979 were prepared. Local people were contacted to collect information about past trends.

Verification of map

Forest cover and land use maps prepared using satellite data were taken to the field for verification and reconciliation of the derived classes. Some of the polygons with mixed response were visited to identify the respective information class. For other areas, stratified sampling was carried out to identify the respective class information. There were a few conflicts between dense and open forests. Some of the patches infested with *Lantana camara* were mapped as dense forest. Some of the patches of plantations were also rectified after completion of mapping.

Change detection and analysis

To assess the changes in spatial and temporal patterns of forest resource distribution and land use, maps were overlaid. Forest cover and land use polygon themes for the three map-years (obtained from visual interpretation) were converted into grid format and imported to Erdas Imagine as image files for further analysis. Maps were overlaid using the matrix option in Erdas Imagine to find changes. Change and no-change matrices were made using attributes of overlain maps for 1979–1990 and 1990–2009. Area of change and no-change, and percent change were also calculated using pivot table in MS-Excel. Transition probabilities were calculated based on frequency distribution of the observations

using the Markov probability equation. The Markov equation computed the probability of LULC changes using transition probability theory. Given the assigned land cover classes, a frequency table was developed by counting the transitions from one class to another with a specified increment. A Markov process can be described by the transition probability function $P(t|x,t_0)$ which represents the conditional probability that the state of a system will be at time t, given that at time t_0 ($< t$) system is in state x (Reddy et al. 2009). Markov process can be expressed as:

$$P\{X_{n+1} = a \mid X_n = a_n, X_{n-1} = a_{n-1}, \cdots\cdots, X_1 = a_1\} \quad (1)$$

Given the past and present LULC classes and their spatial distribution, transition probability matrices were prepared and probabilities of change were calculated. The transition probability matrix describes the system where elements of matrix are individual transition probabilities of one state moving to another state after time or space increment (Weng 2002).

Mapping invasiveness

Mapping and change detection analysis did not bring out significant changes in the landscape. The classification scheme was not able to identify and map such changes. For this, we revisited the study area to identify and map degradation. Interactive meetings were carried out with local people to document the landscape changes over the past three decades. Information gathered from the discussion, field verification, forest cover maps, topographic sheets and spectral response patterns identified using satellite imagery were transferred onto the thematic maps to generate forest cover and land use maps showing invasiveness.

Post change-detection analysis

The changes identified using remote sensing data and field survey were analyzed and summarized. For this, the entire area was studied in three different elevation zones (1) <1,000 m, (2) 1,000–1,500 m and (3) >1,500 m. These three zones were reinterpreted using information gathered from satellite data, forest cover and land use map and field data. Local people were contacted and group discussions were carried out to investigate the changes. Results were summarized as changes occurring in the last three decades using pictorial representation of the area at an interval of four decades (1970 and 2010).

Results and discussion

Forest cover and land use mapping and change analysis

We prepared three forest cover and land use maps with ten classes on the basis of the classification scheme (Fig. 3), ground truth data and interpretation key. The area cover distribution for different classes is given in Table 3. Five forest classes *viz*., evergreen dense forest (density >40%), evergreen open forest (density between 10%–40%), deciduous dense forest (density >40%), deciduous open forest (density in 10%–40%) and scrub (density <10%) were interpreted. Non-forest classes were plantation, agriculture, lake, river and settlement. The study area was covered with dense forest on the higher ridges. Scrub was also distributed uniformly over the study area but was more common around agricultural fields and open forest. Dense forest decreased over the study period while open forest increased, owing to conversion of dense to open forest.

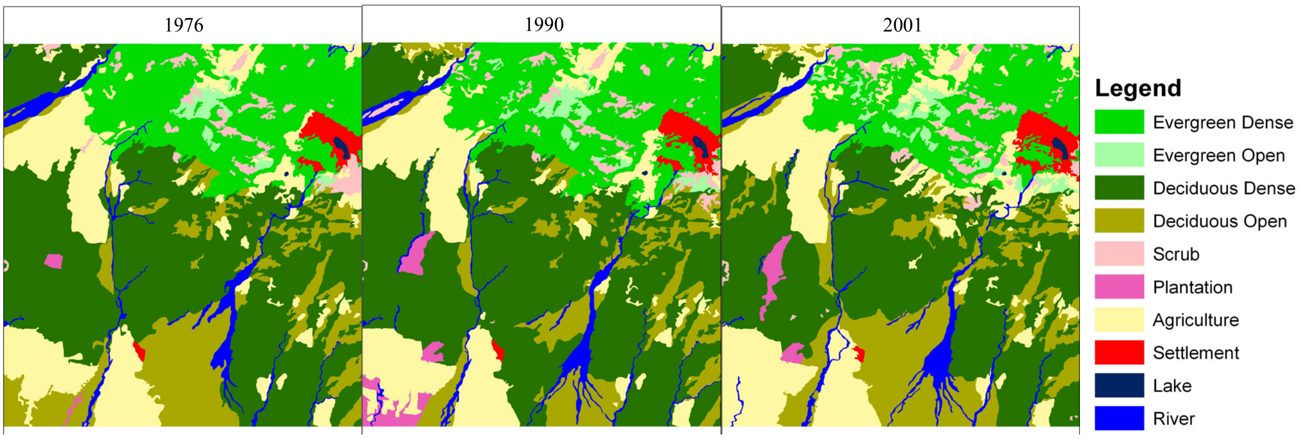

Fig. 3: Forest cover and land use maps in 1976, 1990 and 2001

Among non-forest classes, plantation was in select pockets around settlements and farmland. Farmland was distributed over the entire study area. Aspect is one of the controlling factors in distribution of farmland, others being slope and accessibility from settlements. Farmland was generally located on south and south-west aspects. Plantations were in bright red colour and agriculture in pinkish colour on false colour composite. Predominantly rainfed farming was practised in the area and soils were not very fertile. Some of the low-lying parts of the study area were fertile with relatively better coverage of rivers. In the hilly region large areas were fallow but were mapped together with farmland. Water was generally in narrow streams and rivu-

lets, which were challenging to map in the hilly terrain. Sandy beds occurred in linear patches mostly along river channels. They were quite easy to map owing to contrast to the remaining mosaic. Settlements were distributed throughout the study area but could not be mapped because of their small size and mixing with background classes. However, major settlements such as Nainital Township, Khurpatal and parts of Kaladhungi were mapped. Distribution of forest cover and land use classes in 1979, 1990 and 2009 are given in Table 3. Change area matrix and transition probability of conversion from 1979 to 1990 and 1990 to 2009 are given in Table 4a and 4b, respectively.

Table 3: Distributions of forest cover and land use areas in 1979, 1990 and 2009

Class	1979		1990		2009	
	km^2	%	km^2	%	km^2	%
Evergreen (dense) forest (Ev-d)	71.64	17.91	69.61	17.40	59.93	14.98
Evergreen (open) forest (Ev-o)	4.61	1.15	6.38	1.60	7.11	1.78
Deciduous (dense) forest (Dd-d)	165.13	41.28	168.98	42.25	143.61	35.90
Deciduous (open) forest (Dd-o)	60.1	15.02	46.22	11.56	66.92	16.73
Scrub (Sc)	9.04	2.26	9.63	2.41	10.4	2.60
Plantation (Pl)	0.97	0.24	6.87	1.72	3.69	0.92
Agriculture (Ag)	70.1	17.52	71.6	17.90	87.01	21.75
Lake (Lk)	0.53	0.13	0.53	0.13	0.53	0.13
River (Rv)	12.69	3.17	14.24	3.56	14.2	3.55
Settlement (Set)	5.21	1.30	5.92	1.48	6.6	1.65

Table 4a: Change area matrix from 1979 to 1990 (area in km^2, values in parenthesis are transition probability of conversion)

	Ev-d	Ev-o	Dd-d	Dd-o	Sc	Pl	Ag	Lk	Rv	Set
Ev-d	68.32 (0.95)	1.16 (0.02)	--	--	2.29 (0.03)	--	--	--	--	0.33 (0.0)
Ev-o	0.21 (0.04)	4.23 (0.90)	--	--	--	--	0.28 (0.06)	--	--	--
Dd-d	--	--	162.45 (0.94)	6.33 (0.04)	--	2.08 (0.01)	1.31 (0.01)	--	1.46 (0.01)	--
Dd-o	--	--	5.35 (0.1)	36.85 (0.72)	0.25 (0.0)	3.60 (0.07)	2.84 (0.06)	--	2.25 (0.04)	--
Sc	0.73 (0.08)	1.00 (0.11)	--	0.34 (0.04)	5.89 (0.64)	--	1.27 (0.14)	--	--	--
Pl	--	--	--	0.34 (0.35)	--	0.62 (0.65)	--	--	--	--
Ag	0.36 (0.01)	--	1.17 (0.02)	1.13 (0.02)	0.90 (0.01)	0.56 (0.01)	64.61 (0.93)	--	0.38 (0.01)	0.31 (0.0)
Lk	--	--	--	--	--	--	--	0.53 (1.0)	--	--
Rv	--	--	--	1.23 (0.09)	0.29 (0.02)	--	1.28 (0.10)	--	10.15 (0.78)	--
Set	--	--	--	--	--	--	--	--	--	5.32 (1.0)

Ev-d: Evergreen (dense) forest, Ev-o: Evergreen (open) forest, Dd-d: Deciduous (dense) forest, Dd-o: Deciduous (open) forest, Sc: Scrub, Pl: Plantation, Ag: Agriculture, Lk: Lake, Rv: River, Set: Settlements

Table 4b: Change area matrix from 1990 to 2009 (area in km^2, values in parenthesis are transition probability of conversion)

	Ev-d	Ev-o	Dd-d	Dd-o	Sc	Pl	Ag	Lk	Rv	Set
Ev-d	58.00 (0.83)	1.77 (0.03)	--	0.62 (0.01)	3.78 (0.05)	--	4.66 (0.07)	--	0.49 (0.01)	0.29 (0.0)
Ev-o	0.37 (0.06)	5.19 (0.81)	--	--	--	--	0.82 (0.13)	--	--	--
Dd-d	--	--	137.97 (0.82)	23.96 (0.14)	0.84 (0.0)	1.24 (0.01)	2.20 (0.01)	--	2.76 (0.02)	--
Dd-o	--	--	2.26 (0.05)	37.02 (0.8)	--	--	4.97 (0.11)	--	1.97 (0.04)	--
Sc	1.07 (0.11)	0.05 (0.01)	--	0.53 (0.06)	4.88 (0.51)	--	3.10 (0.32)	--	--	--
Pl	--	--	0.44 (0.06)	--	--	2.45 (0.36)	3.63 (0.53)	--	0.34 (0.05)	--
Ag	0.49 (0.01)	0.1 (0.0)	1.07 (0.01)	1.04 (0.01)	0.9 (0.01)	--	66.77 (0.93)	--	0.87 (0.01)	0.36 (0.01)
Lk	--	--	--	--	--	--	--	0.53 (1.0)	--	--
Rv	--	--	1.87 (0.13)	3.75 (0.26)	--	--	0.86 (0.06)	--	7.76 (0.55)	--
Set	--	--	--	--	--	--	--	--	--	5.95 (1.0)

Ev-d: Evergreen (dense) forest, Ev-o: Evergreen (open) forest, Dd-d: Deciduous (dense) forest, Dd-o: Deciduous (open) forest, Sc: Scrub, Pl: Plantation, Ag: Agriculture, Lk: Lake, Rv: River, Set: Settlements

Evergreen forest

Evergreen forest was distributed on the higher ridges of the study area. It included mixed Pine (*Pinus roxburghii*), Oak (*Quercus* spp.), Deodar (*Cedrus deodara*), Cypress (*Cupressus torulosa*) and mixed high-elevation oak forests. For interpretation of forest resource dynamics, evergreen forest was classified into dense or open cover classes. Area of dense evergreen forest declined over the past three decades from 71.64 km^2 in 1979, to 69.61 km^2 in 1990 and to 59.93 km^2 in 2009. Open evergreen forest increased since 1979. This change was caused by conversion of dense evergreen forest to open evergreen forest. The area of all evergreen forest (both dense and open) declined from 76.25 km^2 in 1979, to 75.99 km^2 in 1990 and 67.04 km^2 in 2009. Change in area from 1979 to 1990 was small but change from 1990 to 2009 was around 8.95 km^2 or 12%. Probability of change in evergreen dense forest increased from 0.05 to 0.17 and in evergreen open forest from 0.10 to 0.19. This we attribute to the relatively high rate of development in the past decade, after the formation of Uttarakhand as a separate state. Ecologically, regeneration capabilities of the forest types have declined. *Quercus* spp. degraded at higher rates due to excessive grazing, timber harvest, and human pressure resulting in lower natural regeneration in the higher regions.

Deciduous Forest

Deciduous forests were distributed on the lower ridges and flat plains of the study area. These included sal (*Shorea robusta*), sain (*Terminalia tomentosa*; *T. alata*), sanan (*Oogenia oogenesis*),

bheemal (*Grewia optiva*), and kweeral (*Bauhinia* spp.). Deciduous forest was classified into dense and open cover classes. Area of dense deciduous forest decreased over the past three decades. It was around 165.13 km^2 in 1979 and decreased to 143.61 km^2 in 2009. Deciduous open forest increased from 60.1 km^2 in 1979 to 66.92 km^2 in 2009. Change in deciduous forest area was due to interchanges between dense and open classes. Overall deciduous forest area declined by less than 15 km^2 or 6% during the study period. Change during 1979-1990 was greater than during 1990-2009. Policy interventions of 1988 and JFM initiatives in the early 1990s achieved a degree of conservation: felling was restricted to selective felling and vigilance in flat terrain for protection was relatively effective. Regions of deciduous forest in the study area were subject to less human and grazing pressure, and this resulting in better conservation and management.

Scrub

Scrubs are forest areas with tree cover less than 10% and typically found on exposed rocks and barren hilly slopes. These areas have less water holding capability and low regeneration potential. Moreover, these are frequently grazed by livestock and used by people because of their accessibility. Temporal mapping identified such patches above 1,100 m. Area coverage of scrub increased over three decades from 9.04 to 10.4 km^2.

Plantation

Plantations are the areas planted by forest department for restoration of forests. These were Teak (*Tectona grandis*) plantations of the 1970s in the reserve forests that have increased in area over the years. The southern part of the study area was planted to Eucalyptus (*Eucalyptus tereticornis*) and Poplar (*Populus deltoides*) plantations by farmers and local people. These plantations are felled at maturity. Plantation area was 0.97 km^2 in 1979, increasing to 6.87 km^2 in 1990, and declining to 3.69 km^2 in 2009. Changes in plantation area are attributed to clearing of planted areas on private lands.

Farmland

Farmland occupied 70.1 km^2 in 1979, 71.6 km^2 in 1990 and 87.01 km^2 in 2009 (Table 3). It was mainly confined to depressions, along gentle slopes and valley sides wherever water sources and soil conditions were favorable. Some agricultural fields were also located on ridges and on steep slopes. There was an increase in agriculture area due to conversion of scrub and low-density pine areas into farmland. Main crops were wheat (*Triticum aestivum*), paddy (*Oryza sativa*), finger millet-mandua (*Eleusine coracana*), Black Soyabean or bhatt (*Glycine soja*), chana (*Cicer arietinum*), and masoor (*Lens culinaris*). Cash crops were potato (*Solanum tuberosum*), peas (*Pisum sativum*), chilli (*Capsicum frutescens*), beans (*Phaseolous vulgaris*), ginger (*Zinzibar officinale*), and Gaderi (*Colocasia esculenta*). Production in these fields typically provided produce only for household use. Select households were able to use production for livelihood incomes. Agricultural woodland was interspersed with farmland due to its value as a resource other than crops. Trees, including oak (*Quercus leucotrichophora*, *Q. floribunda*), walnut (*Juglans regia*), Bheemal (*Grewia optiva*), *Ficus auriculata*, *Ficus nemolaris*, *Bauhinia variegata* were found along edges of farmland. These species were important to villagers as livestock fodder and fuel wood sources, besides, helping to stabilize soils and improving soil moisture.

River and lake

The water bodies were mapped as rivers and lakes. The two largest lakes *viz.*, Nainital and Khurpatal were mapped as lakes. In the river category, Nihal, Baur and parts of Dabka were mapped. There was no significant change in the extent of water bodies. Minor changes between 1979 and 1990 were due to changes in spatial resolution of the satellite data.

Settlement

Settlement occupied 5.21 km^2 in 1979, 5.92 km^2 in 1990 and 6.6 km^2 in 2009. Only the main settlements viz. Nainital township and adjoining areas, Khurpatal and parts of Kaladungi could be mapped. The Himalayan region is known for its scattered settlement pattern but mostly agricultural fields are interspersed with settlements. Thus, the rural areas could not be mapped.

Mapping invasiveness

During field survey and interviews of local people, degradation caused by invasive species was reported. Affected areas were mapped (Fig. 4). Invasive alien species occupied most of the forest areas. Two major invaders affecting the quality of forest resources were identified and mapped.

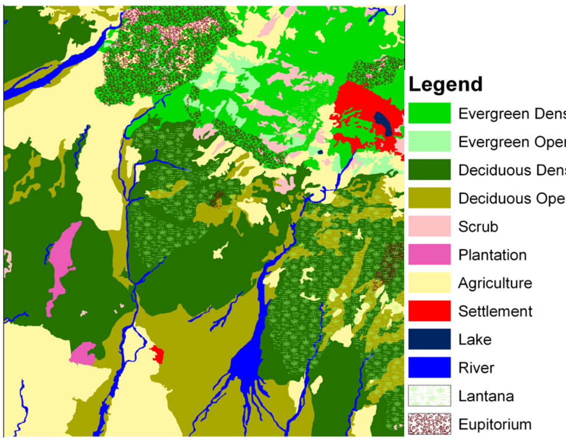

Fig. 4: Forest cover and land use map (2001) showing invasiveness

Eupatorium adenophorum

Presence of *Eupatorium* spp. in open and degraded forests, and in some well-stocked forests was reported by most of the locals in the study area. *Eupatorium* spp. first appeared in the area recently (5−10 years ago). It was earlier confined to elevations below 1,000 m but has invaded areas up to 1,800 m, on wet and moist sites. This contrasts with the spread of the other major invasive alien species, *Lantana camara* which prefers open, sunny areas. *E. adenophorum* was recorded in evergreen forest,

both dense and open. It was not found in pine forest, possibly because of the accumulation of a thick layer of pine needles that precluded seed germination. *E. adenophorum* can colonize areas with low soil fertility. It has invaded scrub and agricultural fields. Few plants were also recorded in dense deciduous forest.

Post change-detection analysis

The impact of resource utilization on the forest ecosystem was evident in LULC maps. The post change-detection analysis brought out three scenarios of forest degradation between 1970 and 2010 as described below.

Low altitude (<1,000 m)

Low altitude landscapes were dominated by broad-leaved forests, although higher ridges of these landscapes at around 1,000 m supported mixed pine forests interspersed with patches of pure pine stands (Fig. 5a). Gentle slopes and low-lying areas supported sal forest with associate species. Earlier habitations were distributed mainly on the low-lying *terai* region where alluvial soils were fertile and irrigation networks were in place. Land was used for intensive farming and livestock rearing. Dependency on forest resources was limited to fuel-wood but some livestock fodder was collected from forests. With the increase in population, habitations expanded in villages at slightly higher elevations (around 1,000 m) in the low altitude zone. Availability of fodder and fuel wood led to increased populations and numbers of households in these villages. This led to increased human degradation of forests. Dense forest areas gradually changed to open forests. Some open forests were showing the presence and preponderance of invasive species notably *Lantana camara* and, more recently, *Eupatorium adenophorum.*

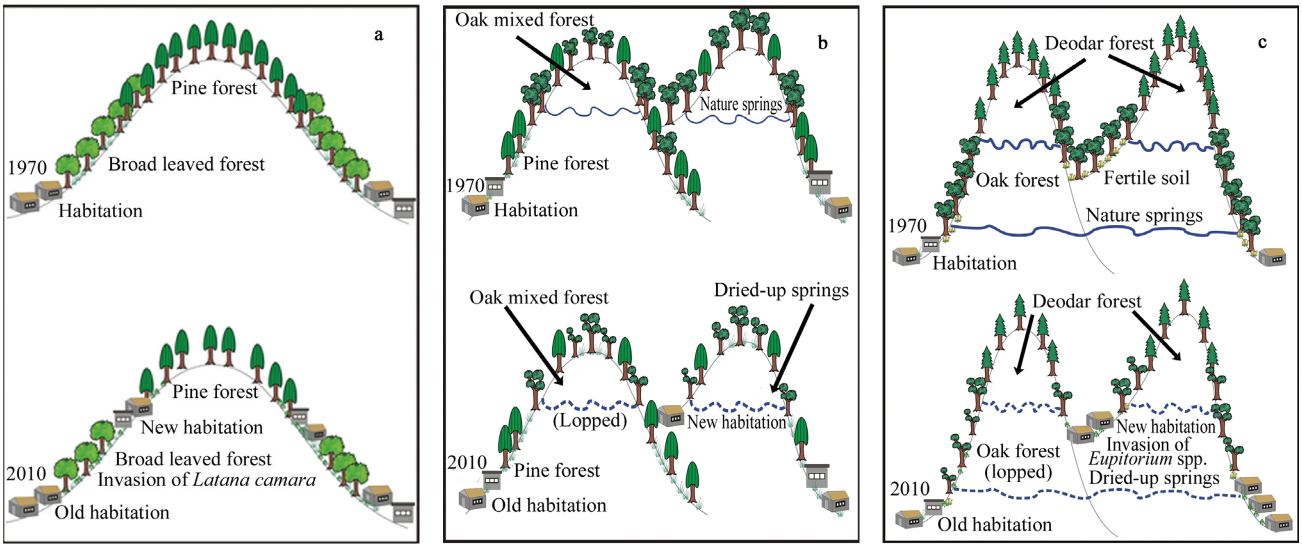

Fig. 5: Dynamics in three different altitudinal zones (a) Low (<1,000m), (b) Mid (1,000–1,500m) and (c) High (>1,500m) for past three decades

Middle elevation (1,000–1,500 m)

The middle elevation zone at 1,000 m–1,500 m supported a combination of mixed pine forest, pure pine forest, and mixed oak forest. Lower elevation areas supported pure pine stands followed by mixed oak - pine forests, though there were few patches of pure oak forest (Fig. 5b). This zone suffered maximum opening of the tree canopy as a result of forest degradation and decline of forested area. Especially oak forests showed signs of heavy lopping and felling/cutting of branches for use as fuel-wood and fodder. Pine forests were more prone to forest fire due to their drier conditions, and also due to setting fires deliberately by local communities for better growth of ground cover during monsoons. Thus, anthropogenic activities increased in area with increased numbers of habitations, opening of tree canopies due to increased extraction and forest fires, and presence of invasive alien species. Habitations increased over the years as population increased, even though the area of farmland remained more or less constant. The main traditional activities of local communities are livestock rearing for milk production and vegetable farming. One of the significant changes in this zone was drying of natural springs and streams. This could be attributed to decreasing quality of oak forests, as maximum disturbance was seen in the oak forests. Earlier studies suggested replacement of oak with pine forests, thus inducing xerophytic conditions. This zone shows evidence of such a phenomenon wherein oak forests were degraded and replaced by pine. Moreover, open sunny areas were becoming infested with *Lantana camara*, whereas moist, shady areas between creeks showed presence of *Eupatorium adenophorum*.

High elevation (>1,500 m)

At high elevations (above 1,500 m) the main forests were mixed oak and conifers including deodar (*Cedrus deodara*) and Cypress (*Cupressus torulosa*). Mainly three species of oaks were recorded, *viz. banj oak* (*Quercus leucotrichophora:* 1,500–1,800

m), *tilonj* or *moru oak* (*Q. floribunda:* 1,800–2,100 m) and *kharsu oak* (*Q. semecarpifolia:* 2,000–2,500 m). Two species of oak recorded at lower abundance were *falyat* (*Q. falcata*) *and riyanj* (*Q. lanuginosa*). A large proportion of coniferous species occurring in the area were planted, some in the British colonial era and some more recently. Planations of *Cupressus torulosa* (cypress) and *Cedrus deodara* were seen in the reserve forests at this elevation (Fig. 5c). Habitations increased at higher elevation, leading to greater anthropogenic pressure. The agriculture sector was dominated by vegetable production. Livestock rearing, which comprised a major activity of people, was dependent on the forest resources to a large extent. Increased extraction of forest resources for fuel-wood, fodder, leaf manure and livestock-bedding material led to general decline of the forest site quality. Forests, therefore, showed signs of disturbance and degradation and the main effect of this was seen in the reportedly poor or nearly absent natural regeneration of oak. Similar to the middle elevation zone, a significant change occurring in high-elevation zone was drying of natural springs and streams. This is attributed to the degradation of oak forests. Our analysis indicates opening of the forest canopy, degradation of forest site quality, reduced natural regeneration of broad-leaved species, and invasion of alien species mainly *Eupatorium adenopharum* even at higher elevations. As a result, ecosystem service potential of these forests declined, as was evident by the drying of natural springs and streams. Perennial streams had begun to dry during summer months, leading to water shortages during the dry season. Forest fires were common in summer months and were said to be the cause of the greatest immediate damage to forest species.

Conclusion

We analyzed the distribution of forest cover and land use around Kaladungi to quantify change over time. Forest cover degradation and conversion were of primary interest. Forest cover was classified as evergreen and deciduous, with phenology and distribution varying with elevation. Each forest was further classified as dense and open forest. Forest departments at state and national levels map forest resources in density classes of dense forest, open forest and scrub. After 2005, the forest density classes have been further refined as very dense, dense, open and scrub.

With increasing anthropogenic pressure, dense forest cover was converted to open forest between 1979 and 2009. In some areas, natural land cover was converted to farmland and the area of settlement also increased. Area of evergreen dense forest decreased while evergreen open forest increased. There were few changes in dense and open deciduous forest cover. Few changes in deciduous forest cover were not unidirectional. This might be due to intervention of forest departments in managing forest areas and bringing new areas under canopy cover by plantation and restoration. However, a distinct class was identified as forest plantation. It also declined in coverage over the study period. Agricultural area and settlements increased over time. Area under open forest increased due to degradation, deforestation and other human interventions in dense forest. There was a higher probability of natural land cover being converted to farmland and urbanized area. It was evident that forest degradation increased from 1979 to 2009.

In comparison with other landscapes of the Himalayan region in India and other tropical regions of the world, the rate of forest cover change at our study area was low. At our study area, limited human usage and other avenues of resource conservation have arrested forest cover change and land conversion. However, indications of degradation were evident. Apart from other invasive plant species, *Lantana* and *Eupatorium* were recorded at high densities and had direct impacts on the structure of the forest. As part of the understory, these species could not be mapped directly using satellite data. Fieldwork was carried out to map the extent and distribution of both invaders. They did not share common habitats, moisture regimes or availability of sunlight.

Some areas under forest and scrub cover were cleared for agriculture or settlement, which indicates that people were the main drivers of change from natural to human-dominated landscapes. These changes might affect the functioning of ecological processes. We conclude that along with mapping of changes, the extent, direction and effect of changes should also be studied to aid in implementing measures to counter adverse changes. Such studies could be used to prepare a land use land cover (LULC) database as a basis for planning, management and utilization of land and other natural resources and future monitoring of related impacts of climate change. The LULC database could be used in policy formulation for conservation and landscape management. These studies could provide useful tools for research, policy formulation, and policy implementation, all of which would enhance management of landscapes and natural resources, and lead to sustainable development and sustainable use of resources.

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